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(71) Applicant: PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(71) Applicant *(for SE only)*: PHILIPS NORDEN AB [SE/SE]; Kottbygatan 7, Kista, S-164 85 Stockholm (SE).

(72) Inventor: LINNARTZ, Johan, Paul, Marie, Gerard; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

(74) Agent: SCHMITZ, Herman, J., R.; Internationaal Octrooibureau B.V., P.O. Box 220, NL-5600 AE Eindhoven (NL).

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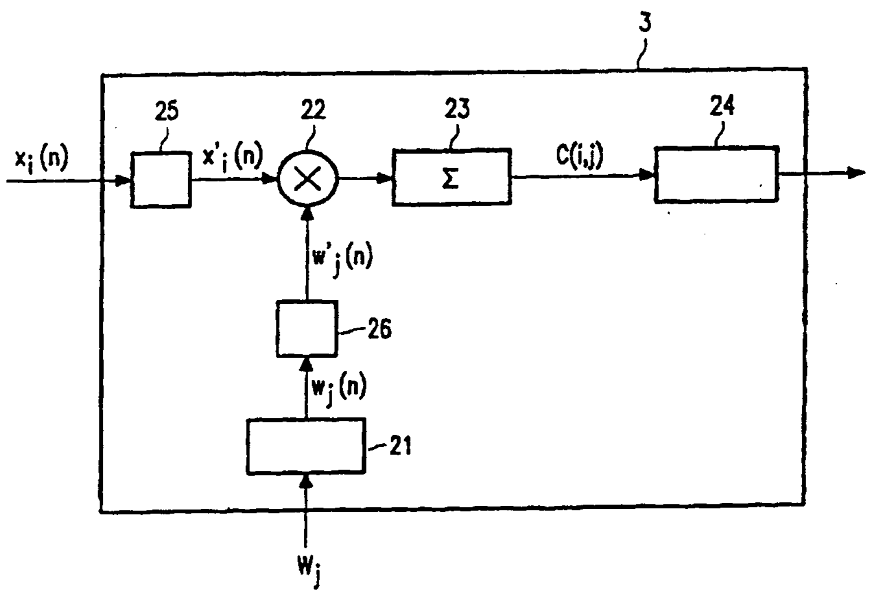

(57) Abstract

A watermark embedded in an information signal is detected by correlating said information signal with a plurality of watermarks $W_j(n)$. The respective amounts of correlation C(i,j) are then evaluated to determine the watermark embedded in the signal $x_i(n)$. The invention provides a significant improvement of the detection by predictive filtering (25) the information signal and/or predictive filtering (26) the applied watermark prior to the process of correlating the signals.

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Detecting a watermark embedded in an information signal.

The invention relates to a method of detecting a watermark embedded in an information signal, comprising a correlation step for correlating said signal and an applied watermark, and an evaluation step for evaluating the result of said correlation. The invention also relates to a method for carrying out said method.

Watermarks are perceptually invisible messages embedded in multimedia content such as audio, still images, animations or video. They comprise information, for example, about the source or copy right status of documents or audiovisual programs. Watermarks can be used to provide legal proof of the owner of the copyright. They allow tracing of piracy and support the protection of intellectual property.

A known method of detecting a watermark embedded in an information signal comprises a correlation step for correlating said signal and an applied watermark. The result of said correlation is then evaluated. For example, if the amount of correlation is larger than a predetermined value, the applied watermark may be considered to be the watermark embedded in the signal. Alternatively, a number of successive correlation steps can be carried out for different applied watermarks. The applied watermark yielding the largest correlation is then considered to be the watermark embedded in the signal.

OBJECT AND SUMMARY OF THE INVENTION

It is an object of the invention, inter alia, to provide a method with which an embedded watermark can yet more reliably be detected.

To that end, the method is characterized by the steps of predictive filtering the information signal or the applied watermark or both, and applying the correlation step to said filtered signal and said filtered watermark.

The invention is based on the recognition that the problem of detecting watermarks closely resembles the detection of weak radio or radar signals in the presence of strong interference or noise. By predictive filtering, i.e. subtracting a prediction of the information signal from said signal, a residual signal is obtained having a significant lower

variance. This means that the interference which the watermark suffers from the residual information is considerably less than it suffers from the original signal.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

Fig.1 shows schematically an arrangement for watermarking a video signal.

Fig.2 shows schematically a prior art arrangement for detecting a watermark embedded in the signal which is generated by the arrangement shown in Fig.1.

Figs. 3 and 4 show schematically arrangements for detecting the watermark in accordance with the invention.

The invention will herein be described by way of an example of detecting a watermark which is embedded in a digital video signal. The watermarks can be added in almost every domain such as, for example, the time domain, the spatial domain, the transform domain after DCT or Fourier transform, etc. In the present example, it is embedded in the spatial domain, i.e. it is added to the luminance pixel values of a digital video signal.

Fig.1 shows schematically an arrangement 1 for watermarking the video signal. The arrangement receives a video signal in the form of luminance samples or pixels p(n) and a watermark W_i. The watermark can be a code which uniquely identifies the owner of the copyright. It can also be a text string or simply a binary coded number. Accordingly, there is a finite set of different watermarks W_i. The arrangement comprises a watermark data signal generator 11 which generates a predetermined watermark data signal $w_i(n)$ for each watermark W_i. The luminance value p(n) and watermark data value $w_i(n)$ are added by an adder **12** pixel-by-pixel. Accordingly, the output signal $x_i(n)$ of the watermarking circuit **1** is:

$$x_i(n) = p(n) + w_i(n)$$

The watermark data signal $w_i(n)$ is chosen such that it is perceptually invisible when the output signal is displayed on a receiver. For example, a small value is added to the luminance of selected pixels p(n) of the video image, the watermark W_i determining the selected pixels. An example hereof will now be given in terms of an image of 8 pixels horizontally and 4 pixels vertically. It is to be noted that the method can also be applied to a predetermined part of the image. The method can also be applied to a plurality of image blocks, each block being associated with a portion of the watermark.

In the present example, the value 1 is added to the luminance of selected pixels whereas other pixels remain unaffected. The following equation denotes a watermark data signal $w_1(n)$ that is generated by watermark data signal generator **11** in response to a first watermark W_1:

$$w_1(n) = \begin{matrix} 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \end{matrix}$$

The following equation denotes a watermark data signal $w_2(n)$ that is generated by the watermark data signal generator if a second watermark W_2 is applied:

$$w_2(n) = \begin{matrix} 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \end{matrix}$$

In this manner, the watermark data signal generator **11** generates a different watermark data signal $w_i(n)$ for each watermark W_i.

In the present example, the video image is assumed to represent a vertical transition from a luminance value 10 to a luminance value 80. The range of luminance values p(n) is assumed to be 0-255. In mathematical notation:

$$p(n) = \begin{matrix} 10 & 10 & 10 & 10 & 80 & 80 & 80 & 80 \\ 10 & 10 & 10 & 10 & 80 & 80 & 80 & 80 \\ 10 & 10 & 10 & 10 & 80 & 80 & 80 & 80 \\ 10 & 10 & 10 & 10 & 80 & 80 & 80 & 80 \end{matrix}$$

Accordingly, if watermark W_1 is applied to arrangement **1**, the watermark data signal $w_1(n)$ is added to image signal p(n), which results in the following output signal $x_1(n)$:

$$x_1(n) = \begin{matrix} 10 & 11 & 10 & 11 & 80 & 81 & 80 & 81 \\ 11 & 10 & 11 & 10 & 81 & 80 & 81 & 80 \\ 10 & 11 & 10 & 11 & 80 & 81 & 80 & 81 \\ 11 & 10 & 11 & 10 & 81 & 80 & 81 & 80 \end{matrix}$$

Similarly, if watermark W_2 is applied to the watermarking arrangement, the watermark data signal $w_2(n)$ is added to image signal p(n), which results in the following output signal $x_2(n)$:

$$x_2(n) = \begin{matrix} 10 & 10 & 11 & 11 & 80 & 80 & 81 & 81 \\ 11 & 11 & 10 & 10 & 81 & 81 & 80 & 80 \\ 10 & 10 & 11 & 11 & 80 & 80 & 81 & 81 \\ 11 & 11 & 10 & 10 & 81 & 81 & 80 & 80 \end{matrix}$$

It will be appreciated that neither the difference between an output signal $x_i(n)$ and input signal p(n), nor the difference between output signals $x_1(n)$ and $x_2(n)$, is perceivable for a human visual system. The output signal $x_i(n)$ is stored on a storage medium such as an optical disc or a magnetic tape, or transmitted through a transmission channel (not shown in Fig.1).

Fig.2 shows schematically a prior art arrangement 2 for detecting the watermark W_i embedded in the signal $x_i(n)$. The arrangement receives a watermark W_j and delivers an indication of whether or not the applied watermark W_j resembles the embedded watermark W_i, i.e. whether i=j or not. The arrangement comprises a watermark data signal generator 21 which is identical to, and produces the same watermark data signal $w_j(n)$ as the watermark data signal generator 11 which is shown in Fig.1. The input signal $x_i(n)$ and the watermark data signal $w_j(n)$ are applied to a circuit which is often referred to as a matched filter or correlator. In the embodiment shown in Fig.2, said correlator comprises a multiplier 22 and a summation circuit 23. The correlator performs the following mathematical operation:

$$C(i,j) = \sum_{n=1}^{N} x_i(n) * w_j(n)$$

in which N denotes the total number of pixels. It will be appreciated that, if the information signal is an analog signal, for example a time continuous signal x(t), the summation circuit 23 will be an integrator.

The correlator output is a number C(i,j) which represents an amount of correlation between the input signal $x_i(n)$ and the watermark data signal $w_j(n)$. In an evaluation circuit 24, the value C(i,j) is evaluated for various watermarks W_j. The watermark W_j yielding the highest correlation is then assumed to be the watermark W_i. Only two different watermarks are considered here.

The correlation C(i,j) can easily be calculated. If watermark W_1 is embedded in the signal, the correlation between $x_1(n)$ and $w_1(n)$ appears to be C(1,1)=736 whereas the correlation between $x_1(n)$ and $w_2(n)$ appears to be C(1,2)=728. Because C(1,1) is greater than C(1,2), the evaluation circuit **24** determines that the embedded watermark is W_1. If watermark W_2 is embedded, the correlation between $x_2(n)$ and $w_1(n)$ appears to be C(2,1)=728 whereas the correlation between $x_2(n)$ and $w_2(n)$ appears to be C(2,2)=736. Because C(2,2) is greater than C(2,1), the evaluation circuit **24** determines that the embedded watermark is W_2. The following Table I summarizes the above results. The rows of this Table denote input signal $x_i(n)$, i.e. the input signal in which a watermark W_i is embedded. The columns denote watermark W_j which is applied to arrangement **2**.

	W_1	W_2
$x_1(n)$	C(1,1)=736	C(1,2)=728
$x_2(n)$	C(2,1)=728	C(2,2)=736

Table I

It will be appreciated from this example that the values of C(i,j) representing the amounts of correlation are close to each other. This means that the detection circuit is vulnerable with respect to noise, transmission errors, coding errors, etc.

Fig.3 shows schematically an arrangement **3** for detecting the watermark W_i embedded in the signal $x_i(n)$ in accordance with the invention. The arrangement comprises the same watermark data signal generator **21**, multiplier **22**, summation circuit **23** and evaluation circuit **24** as are shown in Fig.2. The arrangement further comprises a first predictive filter **25** and a second predictive filter **26**. The first predictive filter **25** is connected between the signal input and the multiplier **22**. It filters the input signal $x_i(n)$ and generates a filtered input signal $x_i'(n)$. The pre filtering process is also called "whitening", similar to filters that decorrelate noise in radar and radio communication receivers.

The second predictive filter **26** is connected between the watermark data signal generator **21** and the multiplier **22**. It filters the locally applied watermark data signal $w_j(n)$ and generates a filtered watermark data signal $w_j'(n)$. The structure of each predictive filter is based on statistical properties of the information signal. Such filters are known per se in the field of source coding. Examples are linear predictive filters as used in DPCM image and speech coding. Other examples are combinations of a transform, a prediction for each frequency subband or transform coefficient, and an inverse transform.

In the present example, in which the input signal is a digital video image, predictive filter 25 predicts each pixel from its neighbours to the left, to the right, above and below. The predicted value is then subtracted from the actual pixel value to obtain a residual value. In mathematical notation:

$$y'(u,v) = y(u,v) - \frac{y(u-1,v)+y(u+1,v)+y(u,v-1)+y(u,v+1)}{4}$$

in which u en v denote discrete pixel positions along the horizontal (u) and vertical (v) axes, y(u,v) denotes filter input samples and y'(u,v) denotes filter output samples. Accordingly, the following equations apply to the filtered input signal $x_1'(n)$ and the filtered input signal $x_2'(n)$, respectively (a scaling factor 4 has been applied to maintain integer values):

$$x_1'(n) = \begin{matrix} 18 & 14 & 7 & -56 & 147 & 84 & 77 & 164 \\ 14 & -4 & 4 & -74 & 74 & -4 & 4 & 77 \\ 7 & 4 & -4 & -66 & 66 & 4 & -4 & 84 \\ 24 & 7 & 14 & -63 & 154 & 77 & 84 & 158 \end{matrix}$$

$$x_2'(n) = \begin{matrix} 19 & 8 & 13 & -57 & 148 & 78 & 83 & 163 \\ 13 & 3 & -3 & -73 & 73 & 3 & -3 & 78 \\ 8 & -3 & 3 & -67 & 67 & -3 & 3 & 83 \\ 23 & 13 & 8 & -62 & 153 & 83 & 78 & 159 \end{matrix}$$

Further, the first predictive filter 25 and the second predictive filter 26 are the same in this example. Although this is a preferred embodiment which yields the best performance, it is not essential. The filters may be different, or one of the predictive filters 25 and 26 may even be dispensed with. The performance of the watermark detecting arrangement is then still significantly better than the perfomance of the prior art arrangement. Accordingly, the following equations apply to the filtered watermark data signal $w_1'(n)$ and the filtered watermark data signal $w_2'(n)$, respectively:

$$w_1'(n) = \begin{matrix} -2 & 4 & -3 & 4 & -3 & 4 & -3 & 4 \\ 4 & -4 & 4 & -4 & 4 & -4 & 4 & -3 \\ -3 & 4 & -4 & 4 & -4 & 4 & -4 & 4 \\ 4 & -3 & 4 & -3 & 4 & -3 & 4 & -2 \end{matrix}$$

$$w_2'(n) = \begin{matrix} -1 & -2 & 3 & 3 & -2 & -2 & 3 & 3 \\ 3 & 3 & -3 & -3 & 3 & 3 & -3 & -2 \\ -2 & -3 & 3 & 3 & -3 & -3 & 3 & 3 \\ 3 & 3 & -2 & -2 & 3 & 3 & -2 & -1 \end{matrix}$$

The following Table II shows the amounts of correlation C(i,j) between filtered input signal $x_i'(n)$ and filtered watermark data signal $w_j'(n)$ corresponding with watermark W_j. It will be appreciated from comparison with Table I that the performance of the watermark detector shown in Fig.3 is significantly better than the one shown in Fig.2.

	W_1	W_2
$x_1'(n)$	C(1,1)=1152	C(1,2)=704
$x_2'(n)$	C(2,1)=704	C(2,2)=952

Table II

Table III shows the amounts of correlation between filtered input signal $x_i'(n)$ and the unfiltered watermark data signal $w_j(n)$, i.e. if the input signal $x_i(n)$ is subjected to predictive filtering only. The watermark data signal $w_j(n)$ is directly applied to the multiplier 22 in this case. As can be seen, the performance is worse than in Table II but still better than in Table I.

	W_1	W_2
$x_1'(n)$	C(1,1)=604	C(1,2)=544
$x_2'(n)$	C(2,1)=544	C(2,2)=588

Table III

Table IV shows the amounts of correlation between the unfiltered input signal $x_i(n)$ and the filtered watermark data signal $w_j'(n)$, i.e. if the watermark data signal $w_j(n)$ is subjected to predictive filtering only. The input signal $x_i(n)$ is directly applied to the multiplier 22 in this case. Again, the performance is worse than in Table II but still better than in Table I.

	W_1	W_2
$x_1(n)$	C(1,1)=604	C(1,2)=544
$x_2(n)$	C(2,1)=544	C(2,2)=588

Table IV

Fig.4 shows a further embodiment of an arrangement 4 for detecting the embedded watermark. In this arrangement, each pixel of the input signal $x_i(n)$ is multiplied in a multiplier 42 by a specific weighting factor. The products are summed up in a summation circuit 43 which delivers the correlation value C(i,j). A calculating circuit 44 receives the applied watermark W_j and generates the weighting factors using a model of the statistical properties of the information signal. In this embodiment, predictive filtering is not applied to the input signal but embedded in the calculation circuit 44.

In summary, a watermark embedded in an information signal is detected by correlating said information signal with a plurality of watermarks $W_j(n)$. The respective amounts of correlation C(i,j) are then evaluated to determine the watermark embedded in the signal $x_i(n)$. The invention provides a significant improvement of the detection by predictive filtering (25) the information signal and/or predictive filtering (26) the applied watermark prior to the process of correlating the signals.

Claims

1. A method of detecting a watermark embedded in an information signal, comprising a correlation step for correlating said signal and an applied watermark, and an evaluation step for evaluating the result of said correlation, characterized by the steps of predictive filtering the information signal or the applied watermark or both, and applying the correlation step to said filtered signal and said filtered watermark.

2. The method as claimed in claim 1, wherein the predictive filtering is adapted to predetermined statistical properties of the information signal.

3. The method as claimed in claim 1, wherein both predictive filter steps are the same.

4. A method of detecting a watermark embedded in an information signal, comprising the step of filtering said signal using filter coefficients determined by an applied watermark, and evaluating the result of said filtering, characterized in that the filter coefficients are further determined by a model of the statistical properties of the information signal.

5. An arrangement for detecting a watermark (W_i) embedded in an information signal, comprising correlation means (22,23) for correlating said signal (x_i) and an applied watermark (W_j), and evaluation means (24) for evaluating the result of said correlation, characterized by a predictive filter (25) for filtering the information signal or a predictive filter (26) to filter the applied watermark, or both predictive filters, and applying filtered signal and the filtered watermark to the correlation means.

6. The arrangement as claimed in claim 4, wherein the predictive filters (25,26) are adapted to predetermined statistical properties of the information signal.

7. The arrangement as claimed in claim 5, wherein both predictive filters (25,26) are the same.

8. An arrangement for detecting a watermark (W_i) embedded in an information signal ($_j$), comprising a filter (41,42,43) for filtering said signal using filter coefficients, calculation means (44) for calculating said filter coefficients in dependence on an applied watermark (W_j), and means (24) for evaluating the result of said filtering,

characterized in that the calculation means (44) are adapted to further determine the filter coefficients in accordance with a model of the statistical properties of the information signal.

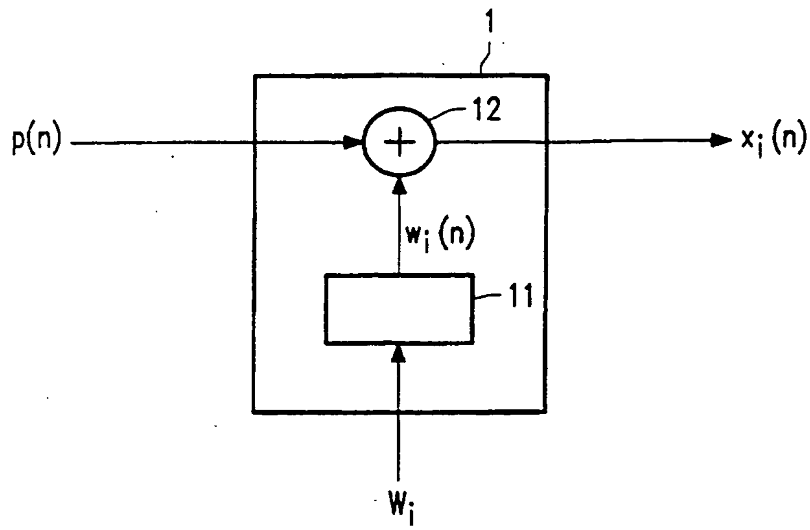

FIG. 1

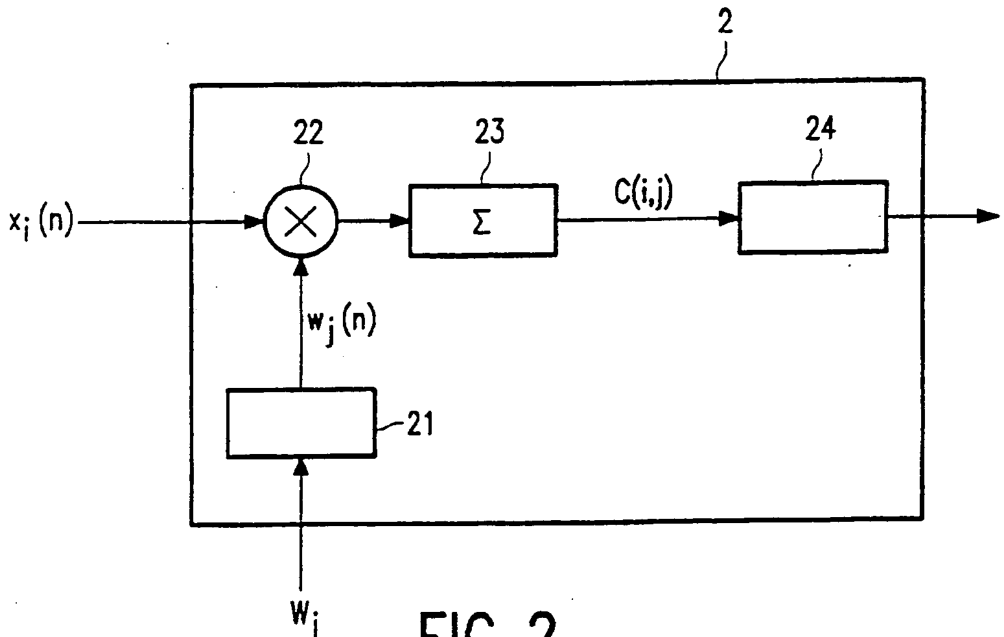

FIG. 2

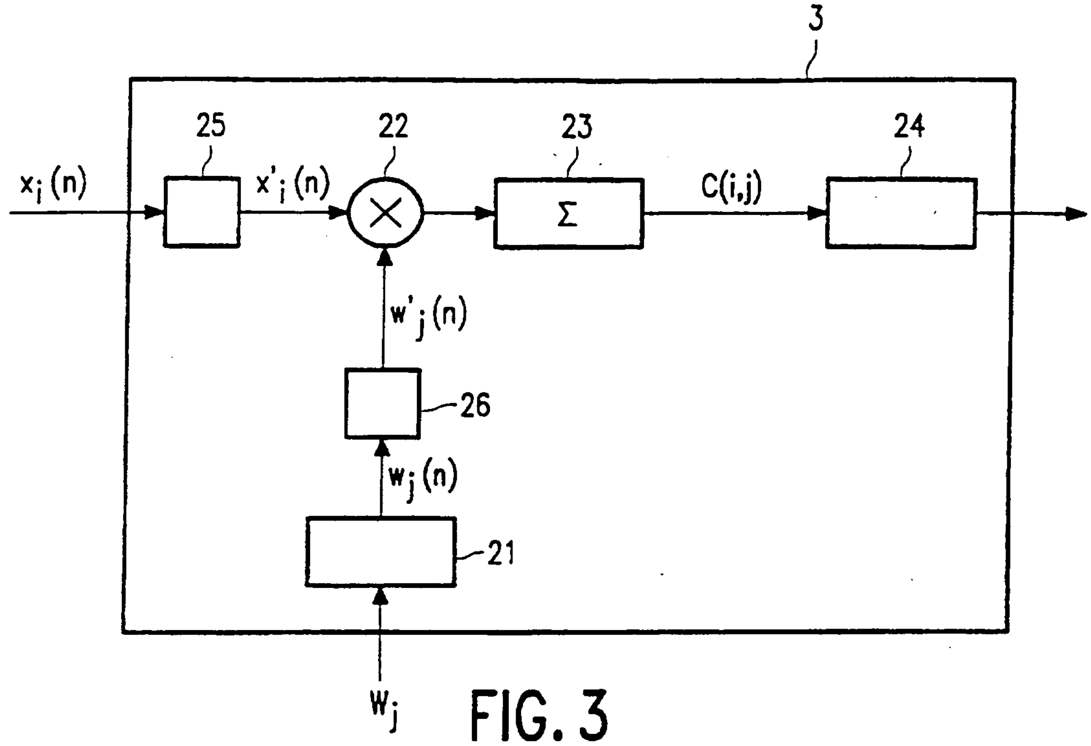

FIG. 3

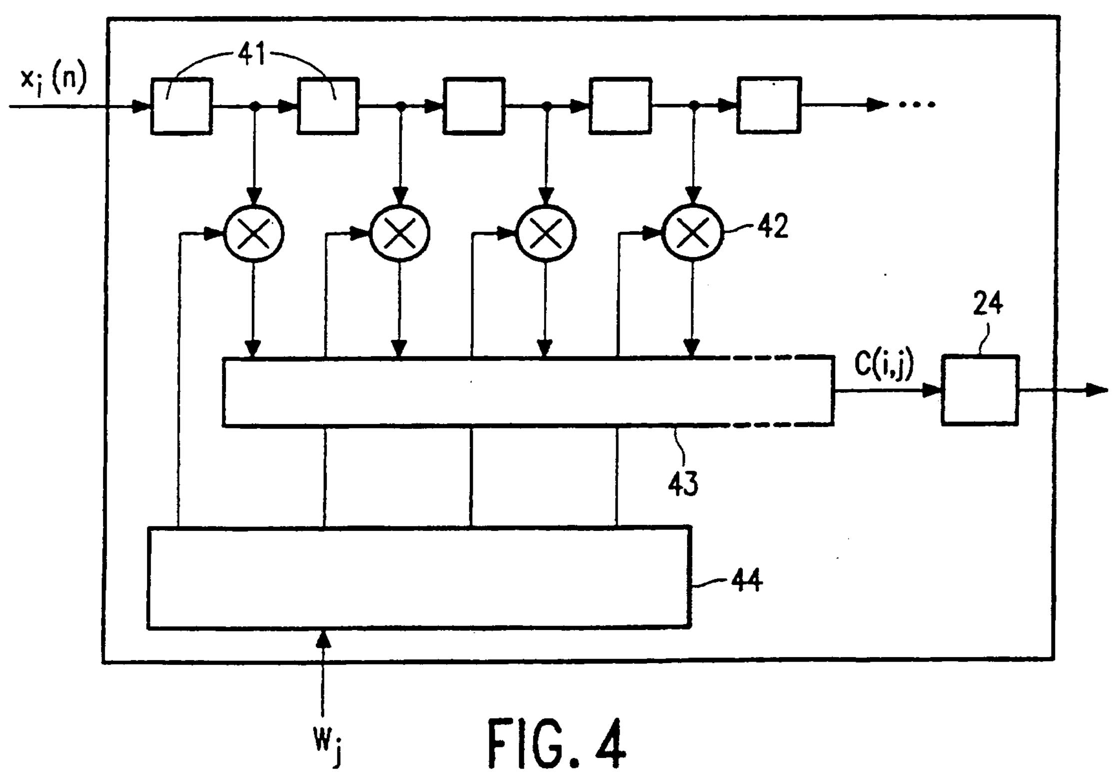

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04N 7/08, H04L 9/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04N, H04L

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WPI,CLAIMS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0766468 A2 (NEC CORPORATION), 2 April 1997 (02.04.97), abstract --	1-8
A	US 5606609 A (HOUSER ET AL), 25 February 1997 (25.02.97), see whole document -- --------	1-8

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INTERNATIONAL SEARCH REPORT
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EP 0766468 A2	02/04/97	AU 6584096 A	10/04/97
		CA 2184949 A	29/03/97
US 5606609 A	25/02/97	NONE	